

Periodic working integrating multipoint gas sampling system for tracer gas measurements

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ABSTRACT

In this paper a new multipoint gas sampling system for tracer gas measurements is presented, which allows the direct deter-

mination of the integral value $\int_{t_1}^{t_2} c(t) dt$. The

system is sampling the air from every measuring point in staggered periods in sampling bags and then the air samples are supplied to the analyzer. In this way you get both a time integrating averaging of the gas concentrations and because of the periodical repetition, information of the trend of $c(t)$.

By an essential measuring time of the analyzer of over one minute, also at high air exchange rates ($>20 \text{ h}^{-1}$), the local age of air can be determined in more than 10 measuring points. Using conventional measuring procedures (discrete measurements of the momentaneous concentration $c(t)$ in time intervals Δt) at high air exchange rates ($> 5 \text{ h}^{-1}$), it is only possible to measure in only one or two other points beside the exhaust.

Measurements with a realized sampling system for 12 measuring points in a test room with a local age of air between 1 and 4 minutes have shown the practical applicability and the advantages of such a system.

INTRODUCTION

Making tracer gas measurements with the help of a gas analyzer and a multiplexer, the number of possible measuring points is limited by the measuring duration of the gas analyzer as well as by the trend of $c(t)$ (high concentration time gradient) in the measuring point. At areas with a low local age of air ($\tau_p < 10 \text{ min}$) as for example in the nearzone of displacement outlets or at high air exchange rates, consequently the

measuring is only possible in 1 or 2 points, partly the system will fail completely. For important ventilation characteristics as eg. the age of air it is not necessary to know the time course of the concentration $c(t)$. Rather it is sufficient to determine directly the time integral

$$\int_0^{\infty} c^* dt$$

(c^* - normalized concentration, see below).

In this contribution, a gas sampling system is presented, where the integral values of the gas concentration is determined by continuous sampling of a measuring gas flow in a collective bag (gas collector) for each measuring point. For this reason the number of possible measuring points is not limited by the initial gas analyzing time and also measurements at extreme short age of air will be possible.

Having conventional measuring methods with time discrete measurements for the determination of the age of air, the concentration courses are integrated numerical. For this a minimum data sampling rate DSR_{min} of about $5/\tau_n$ measuring values (at the trapezoid integrating procedure, about $3/\tau_n$ at interpolation with polynomial of 4th grade; Jung 1998) is necessary. Using a gas analyzer with a minimum analyzing time t_{ana} and a multiplexer, the maximum number of measuring points (trapezoid integrating procedure) results in:

$$N_{max} = \frac{1}{DSR_{min} \cdot t_{ana}} = \frac{\tau_n}{5 \cdot t_{ana}} \quad (1)$$

For example at an air exchange rate of $n = 6 \text{ h}^{-1}$ and an analysis time of 30 s a maximum of 4 measuring points can be analyzed at the same time.

Only some few investigations are known, where by collecting a continuous measuring gas flow over the total measuring time the age of air was determined. However, these experiments were made by extreme high air exchange rates. Therefore after a few minutes a sufficient total measuring time was obtained and no break off criteria was needed. Because of the (relating to the time constant τ_n) long total measuring time of 5 .. 10 τ_n it was not necessary to calculate the residual integral

$\int_{t_{end}}^{\infty} c dt$. Making measurements with small air exchange rates ($n = 2 \dots 5 \text{ h}^{-1}$) the total measuring time lies clearly above 1 hour, so that either you have to measure with extreme small collecting volume flow rates or the total collecting volume gets very large, which makes the handling of the measurement completely impracticable.

With the new developed sampling system the gas collectors are emptied periodically and the gas concentration is determined, so that also an information about the time course of the concentration is available. In this manner it is easy to calculate the residual integral and define a break off criteria for the measurement (eg. $c/c_{start} \leq k_{Limit}$ or reaching of the exponential decay).

MULTIPOINT GAS SAMPLING SYSTEM (Figure 1)

a) Measuring procedure

From each of N_{MS} measuring points in total, a continuous measuring gas flow \dot{V}_{MS} is inspired and collected in a gas collector (collecting bag). Every gas collector is emptied periodically according to time t_{period} . The accumulated gas volume is discharged from the gas collector ($\dot{V}_{ex, coll}$) and mixed with the flow \dot{V}_{MS} from the measuring point during the discharge time and comes to an interim buffer ($\dot{V}_{ex} = \dot{V}_{ex, coll} + \dot{V}_{MS}$). This

discharge time is smaller than $\frac{t_{period}}{N_{MS}}$ so that

within a period t_{period} all gas collectors can be emptied. The buffer is used to get a homogeneous gas mixture, because a stratification of the sampled gas in the primary gas collectors may be caused by the very small measuring flow \dot{V}_{MS} . In addition strong fluctuations of the concentration in the flow \dot{V}_{MS} from the measuring point during the discharge time can be compensated. In a further step the gas sample will be conducted from the buffer to the analyzer.

The concentration of the measuring gas in the buffer corresponds to the mean value of the gas concentration of the integrating period t_{period} :

$$\bar{c}_i = \frac{\int_{t_{period}}^{t_i} c dt}{t_{period}} \quad (2)$$

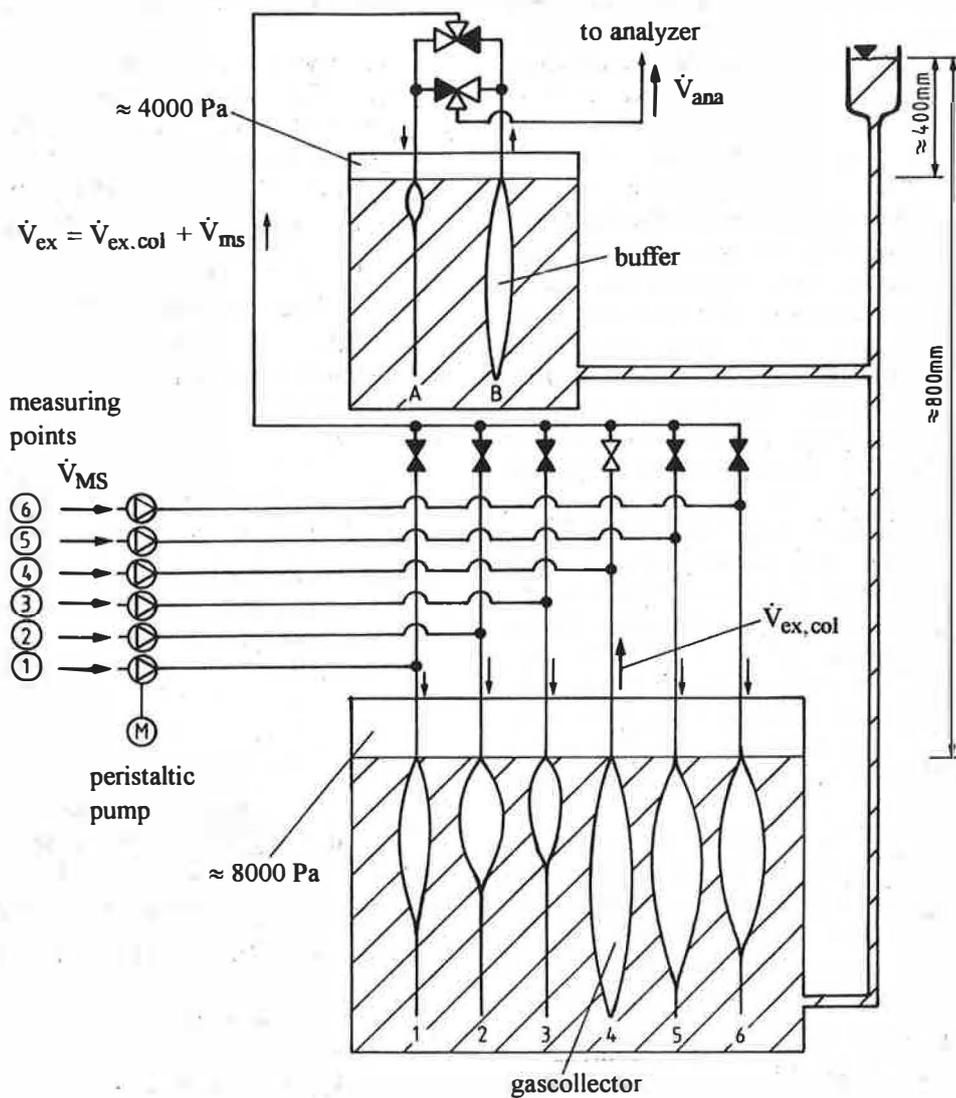
The maximum number of measuring points results from the requirement, that the sampled air volume in the buffer $V_{buffer} = \dot{V}_{MS} \cdot t_{period}$ must be discharged and measured in the analyzer within the time

$t_{ana} \leq \frac{t_{period}}{N_{MS}}$, that means

$$\dot{V}_{ex} \approx \dot{V}_{ana} \geq N_{MS} \cdot \dot{V}_{MS}$$

The total time of the period results from $t_{period} = N_{MS} \cdot t_{ana}$.

As on the one hand very small intake volume flow rates \dot{V}_{MS} in the range of 1-5 l/h and on the other hand very large exhaust volume flow rates \dot{V}_{ex} of more than 100 l/h can be realized without problems, as a consequence there is no restriction for more than 20 measuring points.



Function

actual cycle: exhaust from gascollector 4 and filling in buffer A

exhaust from buffer B (from gascollector 3 in previous cycle) to analyzer

next cycle: exhaust from buffer A to analyzer

exhaust from gascollector 5 and filling in buffer B

Figure 1: Scheme and function of the sampling system

Assuming an analysis time of 30 s and 12 measuring points leads to a time period of 6 minutes. So besides the integral values a good detection of the time concentration profiles is achieved too.

b) Constructive application

The inspiring from the measuring points (up to 12 at a realized system) is made by a peristaltic pump. So a constant flow in the range between a few ml/h and about 15 l/h can be adjusted. The measuring gas is supplied from the top into vertical standing gas collector bags, which are situated in a pressure tank filled with water (overpressure to atmosphere approx. 8000 Pa at the hose inlet). During the discharging process (opening of the corresponding valve) the gas enters into the interim buffer without additional gas pumps using the overpressure. The buffer is constructed identically, but has an overpressure of about 4000 Pa only. Because of the additional hydrostatic pressure of the water in the pressure tank, the collecting bags are emptied from the bottom to the top without having a relevant residual volume.

Using the peristaltic pump and the pressurized tanks for the gas collector and buffer bags, it is possible to work without additional gas pumps. Starting at the peristaltic pump the whole system works with overpressure so that possible leakages in the hose connections or flanges will not influence the gas concentrations.

VENTILATION CHARACTERISTICS

The following ventilation characteristics can be determined using the advantages of the described gas sampling system.

Local age of air

If you select for the concentration course at a step-up or step-down test the following normalized description for $c^*(t)$

$$\text{Step-down } c^*(t) = \frac{c(t) - c_b}{c(0) - c_b} \quad (3)$$

c_b outside concentration/
background noise of the
measuring system
 $c(0)$ initial concentration

$$\text{Step-up } c^*(t) = \frac{c_\infty - c(t)}{c_\infty - c_b} \quad (4)$$

c_∞ final concentration at step-up

so one gets for the local age of air in any measuring point

$$\tau_p = \int_0^\infty c^*(t) dt \quad (5)$$

The gas volume accumulated in the interval $t_{j-1} = t_j - t_{\text{period}}$, t_j in the gas collectors has the following concentration:

$$\bar{c}_j = \frac{1}{t_{\text{period}}} \int_{t_{j-1}}^{t_j} c(t) dt \quad (6)$$

With a corresponding normalisation (as eq. (3) and (4)) for the integral values \bar{c}_j , the local age of air is calculated for a finite measuring time $t_{\text{end}} = k \cdot t_{\text{period}}$

$$\begin{aligned} \tau_p &= \int_0^{t_{\text{end}}} c^*(t) dt + \int_{t_{\text{end}}}^\infty c^*(t) dt \\ &= \sum_{j=1}^k \bar{c}_j \cdot t_{\text{period}} + \int_{t_{\text{end}}}^\infty c^*(t) dt \quad (7) \end{aligned}$$

When the exponential decay is achieved, one can determine the residual integral with the last measured values \bar{c}_k, \bar{c}_{k-1} :

$$\int_{t_{\text{end}}}^\infty c^*(t) dt = \frac{t_{\text{period}} \cdot \bar{c}_k^2}{\bar{c}_{k-1} - \bar{c}_k} \quad (8)$$

For the exponent λ_{exp} of the exponential decay one gets

$$\lambda_{\text{exp}} = \frac{1}{t_{\text{period}}} \ln \frac{\overline{c^*_{k-1}}}{c^*_k} \quad (9)$$

The λ_{exp} is continuously calculated, until a constant value is attained. Then the normalized concentration decreases exponentially and the measurement therefore can be stopped.

Contaminant load factor

In order to determine the distribution of pollutions in a room, normally a constant flow of tracer gas is supplied at the pollution source. With the resulting distribution of the tracer gas concentration (under steady state conditions), the contaminant load factors $\mu_p = c_p / c_{\text{ex}}$ can be determined.

Alternatively to this, the contaminant load factor μ_p can be determined by a pulse-like release of tracer gas by the following equation as well:

$$\mu_p = \frac{\int_0^{\infty} c_p dt}{\int_0^{\infty} c_{\text{ex}} dt} \quad (11)$$

Since at a pulse-likely tracer gas release very fast concentration changes appear, the above described integrals may practically be determined with a sufficient accuracy only by the described procedure with gas collectors.

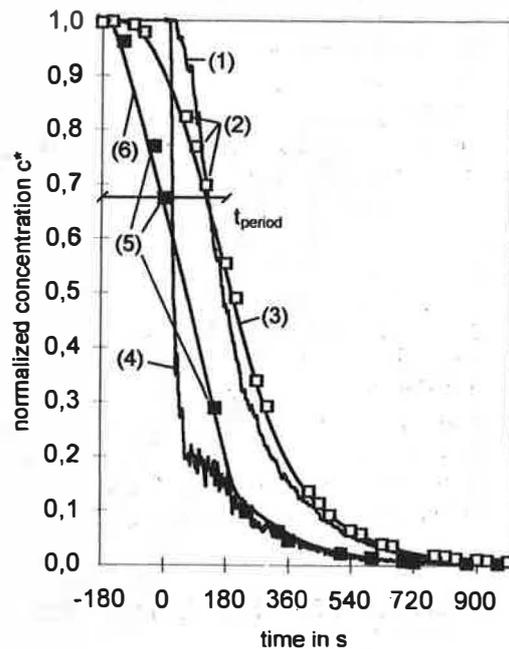
The advantage of this procedure is based on the fact that the measurement times generally can be strongly reduced and such a large amount of tracer gas must not be released, which is of advantage in large halls.

MEASUREMENTS

In a scaled mock-up with displacement ventilation measurements of the local age of air were performed. The air exchange rate was intentionally set to the high value of $n = 16 \text{ h}^{-1}$ ($\tau_n = 3,75 \text{ min}$) to test the sampling system under hard conditions at a low age of air. In the first test sequence the local age of air was measured in two points

(exhaust and occupied zone close to the displacement outlets) with a step-down test using both continuous and integrating measurements. The results are shown in figure 2. The first curve marked (1) is the real momentaneous concentration $c^*_{\text{exhaust}}(t)$, measured with a continuously working gas analyzer. The measurements marked (2) are the results of the integrating measurements with 7 different gas collectors also placed in the exhaust, plotted in the middle of the sampling period t_{period} . Curve (3) is the numerical integrated concentration $C^{**}_{\text{exhaust}}(t)$ as defined in eq. (12).

$$C^{**}(t) = \frac{1}{t_{\text{period}}} \int_{t_j - t_{\text{period}}/2}^{t_j + t_{\text{period}}/2} c^*(t) dt \quad (12)$$

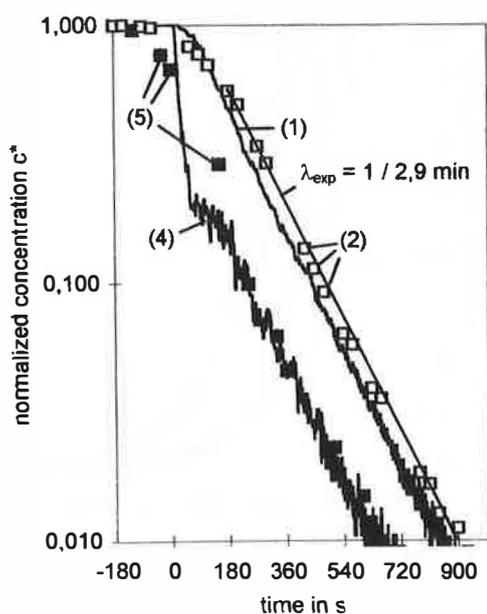


- (1) - exhaust, continuous meas. $c^*(t)$
- (2) - exhaust, integrating meas., gas coll. 1,2,3,5,6,8,9
- (3) -exhaust, $C^{**}(t)$
- (4) - occupied zone, cont. meas. $c^*(t)$
- (5) - occ. zone, integrating meas. gas coll. 4,7,10,11
- (6) - occ. zone, $C^{**}(t)$

Figure 2 Continuous and integrating measurements

The continuous measurement in the occupied zone $c_{occ\ zone}^*(t)$ is marked (4), the results of 4 gas collectors are marked (5) and the calculated $C_{occ\ zone}^{**}(t)$ is shown in curve (6). The good correspondence between the measured integral values (2) and (5) with the corresponding calculated curves (3) and (6) illustrate the accuracy of the 'mechanical integrating sampling system'.

From the same measurements the results (curves (1),(2),(4) and (5)) are shown in figure 3 with a logarithmic ordinate. In this logarithmic form the exponential decay of all concentrations ($c^*(t)$ and \bar{c}_i^* in both measuring points) from about 200 s with the slope $\lambda_{exp} = 1/2,9 \text{ min}^{-1}$ is obvious. This diagram confirms, that the periodical measurements with gas collectors still give a correct information about the time course of the concentrations.



- (1) - exhaust, continuous meas. $c^*(t)$
- (2) - exhaust, integrating meas.,
gas coll. 1,2,3,5,6,8,9
- (4) - occupied zone, cont. meas. $c^*(t)$
- (5) - occ. zone, integrating meas.
gas coll. 4,7,10,11

Figure 3 Exponential decay of concentrations

At a second test sequence in the same room the local age of air was measured in the exhaust and at 11 measuring points located at different heights with 2 step-up and 2 step-down tests using the sampling system with gas collectors. The results are shown in figure 4 plotted as the local age of air in minutes (upper abscissa) and the relative local age of air $\tau_p/\tau_{exhaust}$ (lower abscissa). It has to be pointed out, that the local age of air in all measuring points was in a range, in which normal measuring procedures (without integrating gas collectors) acquiring an analysis time of 60 s will be able to detect the age of air in one point only. The low values $\tau_p < 120 \text{ s}$ in the occupied zone need a maximum scanning interval of $\leq 25 \text{ s}$ (integrating with trapezoid procedure) or $\leq 40 \text{ s}$ (polynomial interpolation) and therefore the local age of air in these points can not be detected even as single measuring points with many analyzers.

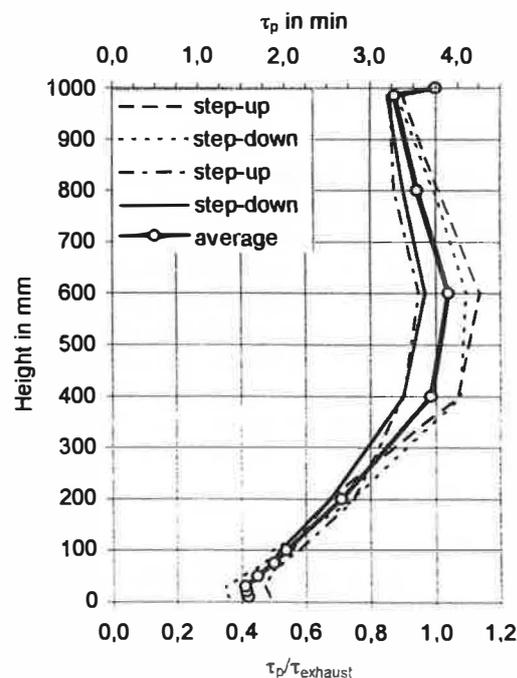


Figure 4 Local age of air

CONCLUSION

The performed measurements have proved the principal applicability of the described gas sampling system for time integrating measurements of the age of air. Further investigations will be done to determine other ventilation characteristics as eg. the contaminant load factor μ_p . This new method makes it possible to get quantitative results about the air distribution in areas with low age of air, as eg. in industrial applications close to displacement ventilation outlets. In most cases the effect of displacement airflow in these areas is only demonstrated qualitatively with eg. smoke tests.

Reference

Jung, A. (1998) Bewertung von Raumluftströmungen mit der Spurengasmeßtechnik.

Ph.D.-Thesis, RWTH Aachen, Germany

